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"Groundwater Heritage and Sustainability"

EXCURSION GUIDEBOOK

The Island of Mljet

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Excursion: The Island of Mljet

Fig. 1 Map of the area with field trip stops

STOP 1: NATIONAL PARK VELIKO JEZERO LAKE

INTERMEDIATE STOPS:

SOBRA DESALINATION PLANT
KOZARICA
BLATSKO POLJE

REGIONAL HYDROGEOLOGICAL SETTINGS OF THE DUBROVNIK - NERETVA REGION

Staša Borović[1] & Josip Terzić[1]

Croatia can, generally, be divided into two very different regions based on their geological settings. The North-eastern part of the country represents the southern margin of the Pannonian Basin System, while the south-western part belongs to the Dinarides. Dubrovnik - Neretva County is the southernmost county in the Republic of Croatia and, in accordance, its structural fabric forms part of the Dinarides. The geological and tectonic settings also dictate the hydrogeological features.

Based on their lithology and age, three dominant types of rocks and deposits can be identified in the area:

1. Carbonate rock complex, encompassing rocks from Upper Triassic, Cretaceous up to Lower Eocene (230 - 40 Ma);
2. Upper Eocene clastic flysch deposits (40 - 34 Ma);
3. Various Quaternary deposits found in karst poljes and the Neretva River delta (<1.8 Ma).

It should be emphasized that carbonate rocks predominate in the region.

The distribution of these deposits reflects the structural and tectonic relationships of the wider area. The regional structural setting is composed of the Dinaric, Epiadriatic and Adriatic structural units of the Dinarides: consecutively positioned from inland toward the shore and islands (Herak, 1991). The current setting is the consequence of the movement of the Adria microplate toward the Dinarides, which resulted in its subduction beneath the Dinarides. In the Dubrovnik-Neretva area, these deposits reach depths of 15-20 km (Aljinović, 1984; Aljinović et al., 1987). On the surface, the Dinaric units are thrust onto the Epiadriatic structural unit. Rock fracturing at the surface is the only manifestation of much greater movements taking place at depth (Prelogović et al., 1999). Hydrogeologically, this area is a typical example of the globally famous karst locus typicus - the Dinaric karst. Geology and tectonics of the Dinaric karst have been described in numerous publications (in addition to those already mentioned see: Prelogović et al., 1995; Vlahović et al., 2005; Korbar, 2009). Due to compressive tectonics dominated by overthrusting and reverse faulting of geological structures, karstification reaches deep horizons in the underground and karstified rock masses are very irregularly distributed. This makes hydrogeological relationships extremely complex; the delineation of catchments is very challenging, and numerical modelling virtually impossible.

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The Dinaric is the most prominent regional structural unit, composed of thick carbonate deposits. A thrust fault front on the surface consists of Triassic dolomites, upon which there is a continuous sequence of Jurassic and Cretaceous deposits, predominantly composed of limestone. The Dinaric unit was thrust onto Epiadriatic fine-grained flysch deposits. The thrust fault front is a regionally prominent geomorphological feature; visible as a carbonate escarpment reaching maximum heights of 500 m. Sub-horizontal tectonic movements are estimated to be up to 10 km (Marković, 1971), which caused the Epiadriatic flysch deposits to be either completely thrust under the Dinaric unit, or eroded. Their extent on the surface of the terrain rarely reaches 1 km in width.

The regional structural unit of the Adriatic comprises carbonate rocks situated to the south of the flysch deposits. A carbonate rock mass comprising the coastal area and the Pelješac peninsula generally represents a monocline structure of dinaridic strike (NW-SE), dipping toward the NE. Dip angles are mostly between 20° - 50°, but can be up to 70° on the Pelješac peninsula. Geological structures on the islands are characterized by their "Hvar" strike (W-E). Carbonate rocks are folded, and small karst poljes were formed in the synclinal parts of the structures.

Seismic activity in the area proves that tectonic movements have not ceased in the neotectonic phase. Maximum expected intensity is 9-10° on the MCS-scale, while 7.5 is the maximum predicted magnitude on Richter scale (Kuk et al., 1987).

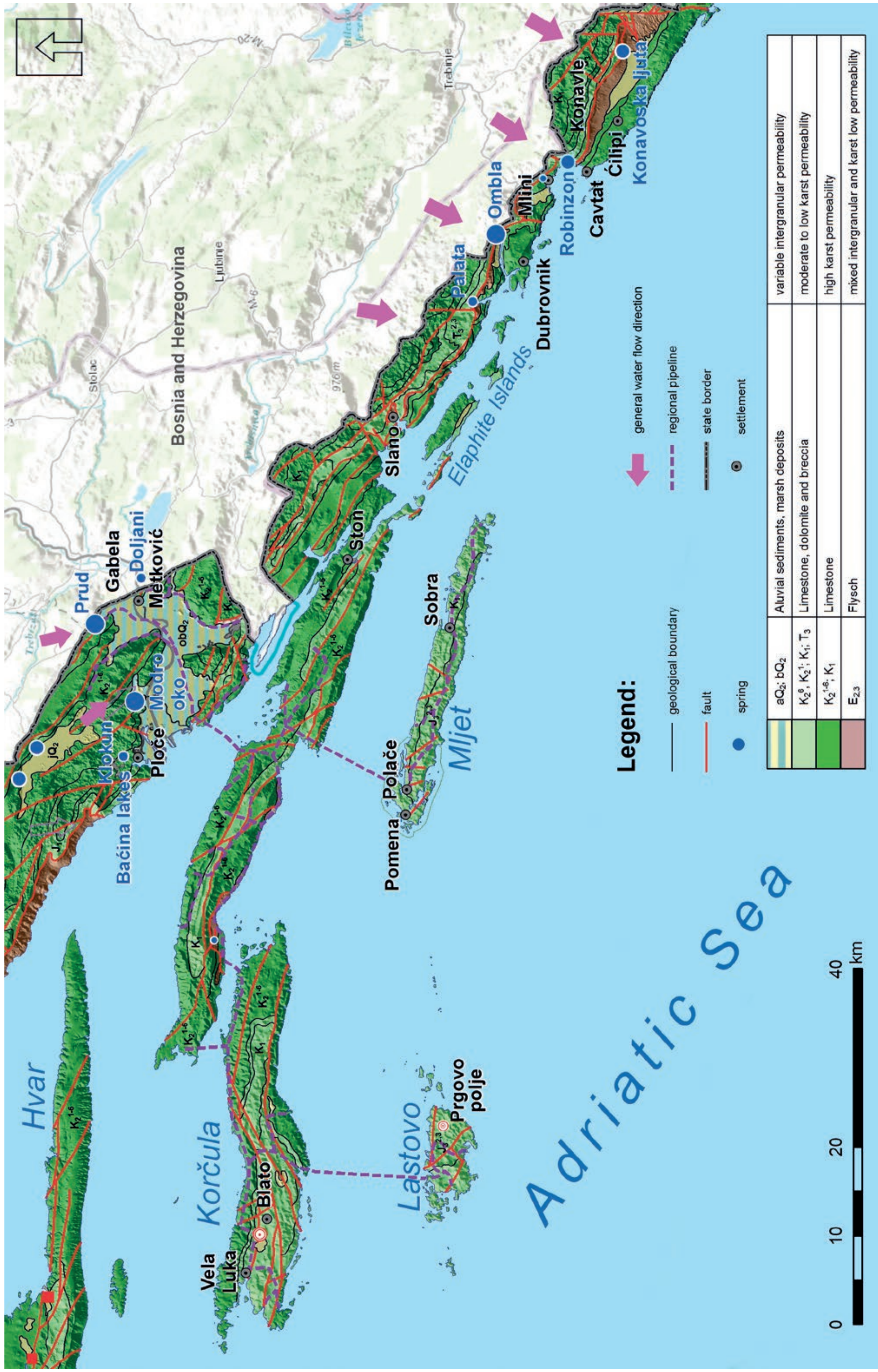

Fig. 2 Hydrogeological map of the area

Deposits in the area can be classified according to their hydrogeological properties into three basic categories: high permeability deposits, low permeability deposits and impermeable deposits.

High permeability deposits are karstified limestones of different ages and they represent the most important aquifers (Fig. 2). Their hydrogeological properties, along with the monocline geological structure and tectonics (which were of paramount importance for the formation of underground flow systems), enabled the formation of large watersheds and high-yield springs in these hydrogeological units.

The carbonate complex also encompasses dolomites in the form of lenses or layers of different thickness. Due to their lithological features, their permeability is lower than that of the limestones. Dolomite zones therefore represent a modifier capable of redirecting groundwater flow within the carbonate complex, which is often called the dolomite barrier.

A narrow coastal zone of impermeable (at the regional scale) flysch deposits is locally very thick (up to 500 m). In the coastal area between Slano and Konavle it represents a total hydrogeological barrier to karst groundwater flow, although some lithological members within the flysch can be permeable. Such a continuous flysch belt effectively disables scattered outflow of fresh water from karst aquifers in the hinterland into the sea. This explains why the majority of discharge occurs through a few large karst springs and there are no significant vruljas (submarine fresh water springs). The most important springs in the area are: the Ljuta spring in Konavle (providing the water supply of the Grude area, used for water bottling and acting as a strategic groundwater reserve), the Robinzon spring in Duboka Ljuta/Plat (for the water supply of Župa Dubrovačka, Kupari, Cavtat, Ćilipi and the surrounding area), the Zavrelje spring at Mlini (acting as the water supply for Mlini and a small hydroelectric power plant), the Slavjan spring in Brgat (previously used for the water supply of Dubrovnik - an aqueduct led to Onofrio's fountains in the town), the Ombla spring in Komolac (providing the current water supply of Dubrovnik with the possibility of hydroelectric power plant construction), the Palata spring in Mali Zaton (for the water supply of Zaton, as well as the Elafite islands off the coast), together with springs in Orašac, Trsteno, Slano, and dozens of smaller springs with intake structures supplying smaller settlements.

From Slano to the NW, the flysch barrier tectonically disintegrated so the majority of the groundwater discharge from the hinterland occurs in the form of small coastal springs and vruljas, which results in their low potential for utilization in larger-scale water supply systems. The most significant discharge area is in the Kuti bay in the internal part of the Ston bay, and in Bistrina bay (Bojanić & Ivičić, 1984). The constant inflow of fresh water is lowering the salinity of the bay which, combined with the sparse population and the lack of industrial facilities (i.e. low pollution levels), has enabled ideal conditions for growth of clams, so the aquaculture of mussels and oysters is a significant source of income in the area.

The Neretva River delta downstream from Metković is a marshy cultivated area, suitable for fruit and vegetable production. Both the surface and shallow subsurface deposits are composed of medium and low permeability clastic deposits. On the surface, clayey silt and clayey sand rich in organic materials predominate, while in the lower horizons gravels with conglomerate intercalations are present. There are three identifiable aquifers along the depth of the Neretva River alluvium (Vidović, 1968). The total thickness of the alluvium is 120 m, and it is underlain by carbonate rocks. The water supply of the town of Neum comes from two drilled wells close to Gabela, north of Metković (Slišković et al., 2002).

On the left bank of the Neretva River a number of springs appear: the Doljani spring (providing the water supply for Metković), as well as the Mlinište, Mislina, Bađula, Bili vir and other smaller springs. These are ascending springs in which water upwells through fractures and forms small lakes on the surface. These springs drain the water from a large carbonate watershed extending as far as Popovo polje with the swallow holes in the Trebišljica River Valley and waters from the compensation basin of Hutovo, built for the Čapljina hydroelectric power plant.

On the right bank of the Neretva River the most significant springs are the Klokun (near the Baćina Lakes, providing the water supply of Ploče), the Modro oko (for the water supply of Desne village) and the Prud (supplying both Metković, and the extensive regional water pipeline NPKL: Neretva River - Pelješac Peninsula - Island of Korčula - Island of Lastovo).

In the NE part of Jezero polje there are a number of contact springs, with the largest ones being the Butina, Stinjevac and Lukavac springs. Only the Butina is used for water supply. The Pelješac peninsula has a few sources of water supply. The Ston area receives its water supply from the Studenac spring in the Ston polje. The rest of the peninsula uses small local pumping sites such as Žuljana, Trpanj and Orebić, or water from the regional NPKL pipeline. The Eastern part of Korčula Island also gets its water supply from the regional pipeline, while the central and western parts of the island use the Blato pumping site with dug wells (Terzić, 2006). Lastovo and Mljet islands use desalinated water from boreholes in the Prgovo polje (Lastovo) and blatinas (specific karst lakes on Mljet).

Acknowledgement: The overview of regional hydrogeological settings was written as a review on the basis of published and unpublished materials listed in reference list and the authors would like to thank all colleagues who contributed.

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THE ISLAND OF MLJET

Ivana Turalija[2]

The Island of Mljet is the most forested island in the Adriatic and one of the most beautiful pearls of the Mediterranean. Untouched nature, the island's mysticism, olive groves, vineyards and rich forests are ideal places to research the rich flora and fauna, and to peacefully enjoy the pristine beauty of the natural surroundings.

Mljet was already mentioned in the fourth century BC in Greek writings, and numerous Greek amphora and shipwrecks along the coast of Mljet are evidence that Greek sailors stayed on the shores of this island during their journeys.

Fig. 3 Blace beach (photo courtesy of Mljet Tourist Board)

[2]conTres, Zagreb, Croatia

Fig. 4 Ulysses's cave (photo courtesy of Mljet Tourist Board)

Mljet National Park is the most important protected area of the Dalmatian south and the oldest national park in the Adriatic. The park covers the western part of the island, which many regard as the most alluring, full of lush and diverse Mediterranean vegetation. The park includes two deep bays which, due to their extremely narrow links with the sea, are regarded as, and indeed named, lakes: the Veliko jezero Lake and the Malo jezero Lake. On an islet of St. Mary in the middle of Veliko jezero lake, there is an old Benedictine monastery.

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Preserved from the Illyrian period, there are many fortifications and tombs, and the best preserved are those on the hill of Veliki Gradac, Veliko jezero and the fortress at Vodice, above the fresh water spring in Vodice next to Babino Polje. The Roman palace, which is the largest after the Diocletian's palace in Split, is part of the valuable cultural heritage of the island of Mljet.

Fig. 5 The Islet of St. Mary (photo courtesy of Mljet Tourist Board)

STOP 1: NATIONAL PARK VELIKO JEZERO LAKE

Palaeolimnological reconstruction of the Veliko Jezero Lake

Ivan Razum[3], Slobodan Miko[1], Nikolina Ilijanić[1], Ozren Hasan[1], Dea Brunović[1], Martina Šparica-Miko[1], Ursulla Rohl[4]

Introduction

Veliko jezero Lake, with a surface area of 1.44 km^2 and a maximum depth of 46 m consists of three basins. It is a marine lake (Govorčin et al., 2001, Sondi & Juračić, 2010) which is connected with the sea through a narrow (10 m) and shallow (2.5 m) Soline channel. Since water exchange is driven solely by tidal currents, which have a very small tidal range, the residence time of water in the lake, according to Buljan & Šipan (1976), is roughly estimated as between 8.5 and 21.5 years if 50 and 80% of the discharged water is returned respectively. The lake is oligotrophic (Hrustić et al., 2013) with a pronounced thermocline during summertime, which occurs between 10 and 15 m depth (Benović et al., 2000). The salinity of the lake varies annually between 38.1 - 38.4‰ (Kružić, 2002) and its annual temperature variations (10.6° to 27.5° C) are presented in detail by Vilibić et al. (2010). In the NW part, Veliko jezero is connected to the Malo jezero Lake through a small channel.

The Veliko and Malo jezero lakes have been the subject of continuous scientific research for more than a century. A first glimpse of the surrounding geology was given by Schubert (1909), while Vuletić (1953) described the geological characteristics and suggested that aragonite is precipitating in Malo jezero. Seibold (1958) recognized that laminated sediments in Malo jezero consist of over 3000 annual layers which he described thoroughly, although he had mistaken aragonite for calcite. Aragonite precipitation was proposed again by Juračić et al. 1998 and Sondi et al. (2000) and explained in detail by Sondi & Juračić (2010). A great deal of work has been done in Holocene environmental reconstructions and lake development using pollen and diatom analysis (Beug, 1961; Jahns & Van den Bogaard; 1998, Wunsam et al., 1999). Two discrete layers of tephra were discovered in Veliko jezero with the older being ascribed to the Mercato-Ottavino eruption 7910 ± 100 B.P. (uncalibrated) (Jahns & Van den Bogaard, 1998; Wunsam et al. 1999). Besides palaeolimnological studies, numerous biological research was also conducted on the Mljet lakes, since the Soline channel is host to the largest coral reef in the Mediterranean (Kružić & Požar-Domac 2002). New geochemical, mineralogical and chronological data obtained from a sediment core from Veliko jezero are briefly presented here.

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[1] Croatian Geological Survey, Zagreb, Croatia
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Composition of the core

The composition of the core varies and reflects the different sedimentary environments represented in it. A marine sequence is characterized by high calcite abundances with some minor detrital input. Organic matter in the marine sequence is mainly of authigenic origin and its concentrations can reach up to 3%. In the lake sequence, aragonite precipitation, which probably caused whitening effects, occurs. In this sequence, organic matter, with a fairly low C:N ratio (around 10) can have concentrations up to 10%. In palaeosols silicate minerals predominate. In the silt and sand sized fractions, quartz is a dominant mineral phase, with minor quantities of feldspars. Organic matter concentrations are below 0.5%, with the average C:N ratio above 17, which implies a detrital provenance of the organic matter. Geochemical variations of Ca and Al as authigenic and detrital elements respectively are presented in Fig. 7. Data were obtained by a linear XRF core scanner at 1 cm resolution.

Fig. 6 Sediment core from Veliko jezero

Chronology of the core

The core (Fig. 7) was retrieved from the deepest part of the lake and its chronology is based on C-14 dates and tephra correlations. Four C-14 dates were obtained in total, two dates are from charred material, one from a plant and one from mollusc shell. In addition to C-14 dates, 10 tephra/cryptotephra layers were observed and six have so far been successfully correlated with known eruptions. Sources of tephra are the Holocene eruptions of Vesuvius and Campi Flegrei volcanoes. All of this was done to establish a relatively firm chronological model of the sediment sequence.

Development of the lake

Our findings and conclusions regarding lake development, based mostly on the geochemical and mineralogical data, are similar to those of Wunsam et al. (1999). The sediment sequence starts with a palaeosol sediment interlayered with thick Neapolitan Yellow Tuff tephra (14.6 ka BP). Based on heavy mineral analyses, parent material for paleosoil is derived from aeolian sands deposited on the SE part of the Island mixed with minor influence from recent soils (Fig. 8).

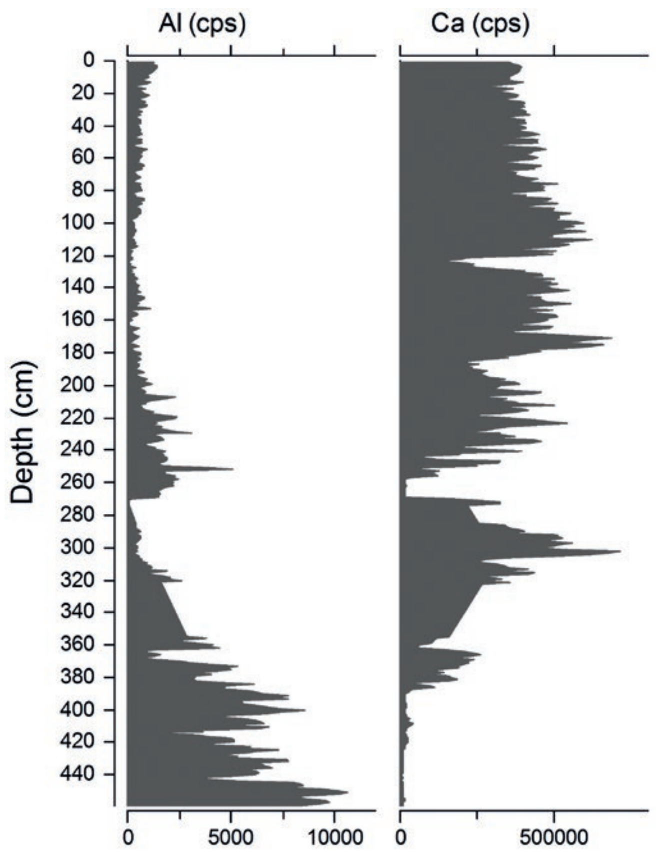

Fig. 7 Geochemical variations of Al and Ca throughout the core

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During the Holocene sea level rise, a salt marsh was formed which existed for approximately 2 ka after which the lake started to form. In the first stage the lake was shallow, slightly brackish with a limited marine influence, represented in the core by the interval from 345 to 305 cm. In the second stage, the lake became more influenced by marine waters, probably due to the rising sea level which led to an increased connection between sea and lake through highly permeable karst, which also led to the deepening of the lake. In this stage aragonite precipitates and some diatom species (N. oblonga), together with the increase in some redox sensitive elements, indicates possible anoxic conditions (interval from 300-275 cm). In the third stage, a massive fresh water intrusion occurred. After the deposition of the Mercato tephra (tephra at 250 cm), during stage four, an increase in salinity was observed over a short interval (from 250-222 cm). Conversely, in stage five a decrease in salinity occurred as a result of freshwater inflow (interval from 222-185cm). In the last stage 6, the marine influence is increasing as a result of sea water intrusion through the Soline channel, initially only during high tides (the interval from 185-123 cm). Finally, a marine intrusion occurred through the Soline channel at a core depth of 123 cm (3.3 ka BP) and the lake ceased to exist. At first, after the sea water intrusion oxic sediment conditions are met, but soon, due to the isolation of the basin, sediment conditions started to be suboxic to anoxic.

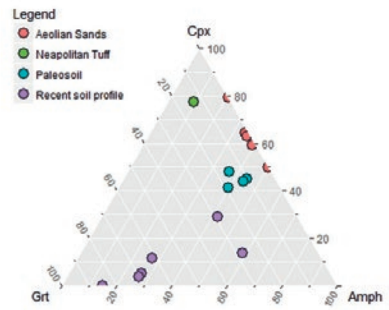

Fig. 8 Heavy mineral data for selected samples. Grt-garnet, Amph-amphibole, Cpx-clinopyroxen

INTERMEDIATE STOPS

Hydrogeological setting of the Island of Mljet and its impact on the organization of the water supply

Staša Borović[1] & Josip Terzić[1]

Structural and lithological settings

The Island of Mljet is one of the lower ranked tectonic units of the southern Dalmatian islands tectonic unit, the structure of which does not differ significantly from the mainland structures. However, in the island area the most significant regional contact (thrust fault) is between the Adriatic and the southern part of the Adria microplate (Herak, 1991; Prelogović et al., 2001 and 2003). It can be stated that the area is tectonically extremely disintegrated, and Mesozoic deposits were already folded during the Jurassic and Cretaceous periods (Kimmerian orogeny). The most significant disturbances occurred during the Laramide orogeny at the transition from the Cretaceous to the Tertiary period, when the basic tectonic units were formed. During the Pyrenean orogeny at the transition from the Tertiary to the Quaternary, the terrain took on the main outlines of its contemporary appearance of an en echelon thrust structure, a part of thrust and fold belt of the Adriatic foreland basin. Only the topographically highest structures have remained above the recent sea level as islands (Korolija et al., 1977).

The structural fabric of the Island of Mljet is basically simple: it is a monocline dipping toward the N and NE, probably the northern limb of an overturned anticline. The strike is WNW-ESE, and the axis is considered to be around the SW shore of the island, i.e. the whole southern limb is submerged under the sea (Korolija et al., 1977). The only prominent fault is a reverse fault along the SW shore of the island, which is also submerged. It is a boundary fault of the lower ranked structural units inside the Adriatic (Vis – Lastovo - Mljet fault), while the contact with the regional structural unit of the Adria microplate is about 10 km off the SW coast of Mljet (Vis – southern Adriatic fault) (Terzić, 2006). The majority of faults have normal and diagonal strike relative to the fold axis. Although numerous, they are not very intensive, so the dominant fold structure is mostly preserved.

Chronostratigraphic units are presented here according to Korolija et al. (1977). The oldest deposits on the Island of Mljet are of Jurassic age, and can be observed at the surface from Polače in the W to Dugi rat in the E. Kimmeridgian-Tithonian deposits are fine-grained limestones, deposited mechanically (calcilutite), with a high $CaCO_3$ content, reaching around 250 m in thickness. However, the most characteristic Jurassic deposits are the Upper Jurassic (Tithonian) dolomites with rare occurrences of limestone interlayers. The dolomitization process destroyed the majority of the primary limestone structures, but in some localities calcilutites were identified. The thickness of the deposits is around 800 m.

[1] Croatian Geological Survey, Zagreb, Croatia

Lower Cretaceous deposits also extend in a belt from the western to eastern shores of the island. Barremian and Aptian deposits lie transgressively on the Malmian deposits. They are mechanically deposited calcilutites and calcarenites. Calcilutites contain up to 98% $CaCO_3$, while biocalcarenites contain well sorted material. Their thickness is around 400 m. Albian limestones have a different fossil content, contain dolomite interlayers, and are around 200 m thick (Fig 9).

Upper Cretaceous deposits stretch all along the northern coast of the island. They are lithologically very similar to the Lower Cretaceous deposits, but can be distinguished by their micro- and macrofossil content. Cenomanian and Turonian deposits are present on Mljet itself, while Senonian sediments are submerged, but can be observed on the islet of Glavat off the N coast of Mljet.

Tertiary deposits are not present on Mljet, and the Quaternary is represented by terra rossa and aeolian sands in small karst poljes.

In 2016, a new geological map of the Island of Mljet was published (Husinec et al., 2016), which encompasses the whole island at the scale of 1:50,000. The novelty is that it uses a lithostratigraphic, instead of chronostratigraphic approach. Since the lithostratigraphic approach gives a much better overview of the areal distribution and correlation of members and units, it will certainly serve as an improved basis for future hydrogeological research.

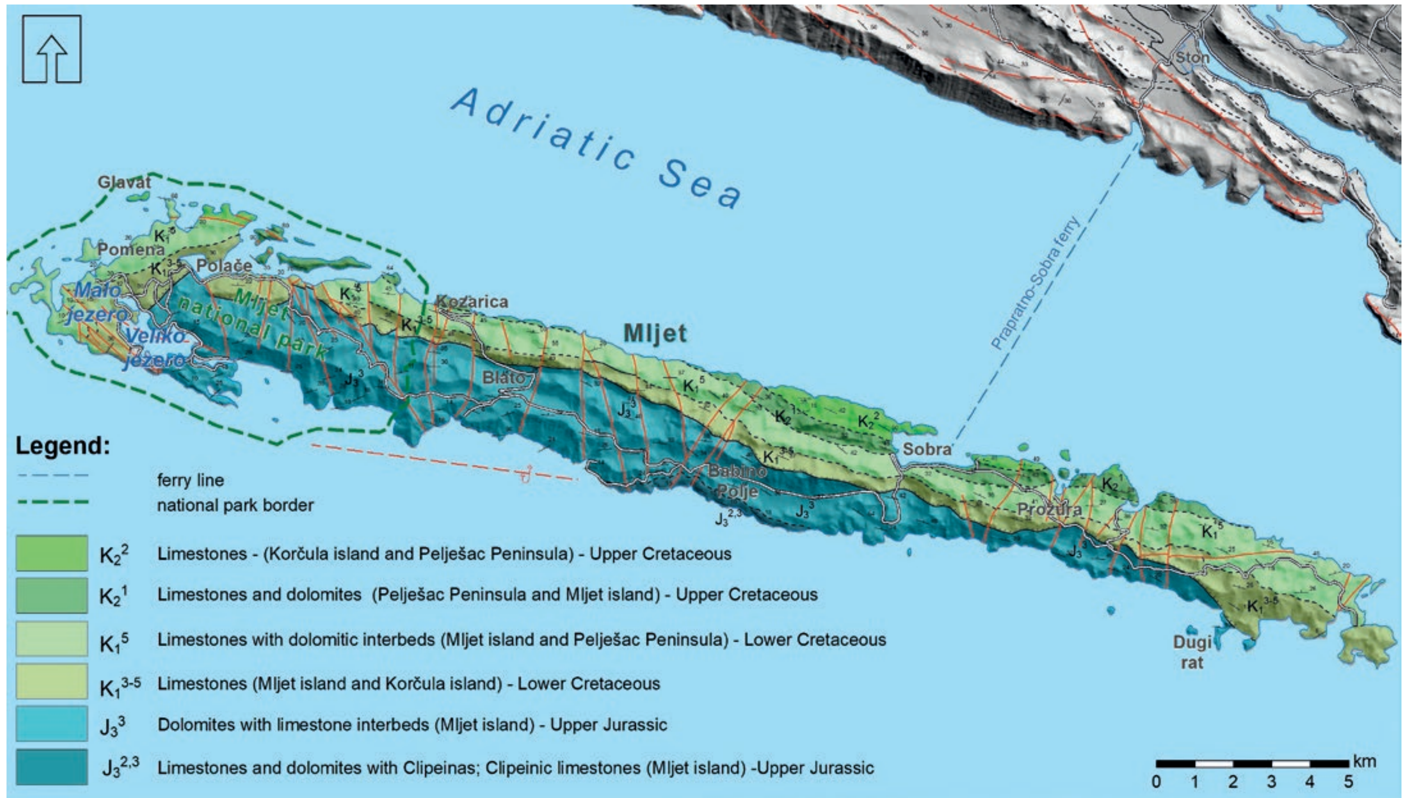

Fig. 9 Geological map of the area

Hydrogeological settings

In a hydrogeological context, the afore-mentioned Jurassic and Cretaceous limestones and dolomites can be described as having different hydrogeological properties and functions. The dominant type of porosity is secondary, fracture porosity. In limestones the fracturing was followed by intense karstification, which is much less pronounced in the dolomites (Fig. 10). Furthermore, on the surface the limestone is more prone to corrosion which results in typical karst forms, while the dolomite is predominantly mechanically weathered into milder morphological forms. On islands of this size, the relatively lower permeability of the rock mass (dolomitic limestones or dolomites) is more suitable for fresh or brackish water accumulation in the underground, than the highly karstified limestones, because in highly permeable rock masses seawater intrusion would be complete and there would be no aquifers or lenses of fresh groundwater significant in the context of providing public water supply.

Because of such permeability contrast between the Jurassic (predominantly) dolomites and Cretaceous (predominantly) limestones, the dolomites represent a relative hydrogeological barrier on the island. The island's monocline structure dipping toward the N and NE, combined with its elongated shape and zonal structure with dolomites in the SW and limestones in the NE, causes waters which infiltrate into the limestones to flow toward the NE and discharge in a scattered manner along the NE coast in the form of vruljas and coastal springs of increased salinity (Goatti, 1996).

Although there are some minor permanent and intermittent fresh water springs on the Island of Mljet, from a hydrogeological point of view the most impressive phenomena by far are the blatinas. These are marshy brackish lakes situated next to either the ponors (swallow holes) of karst polje (as in the Blatsko polje) or submerged sinkholes (as in Sobra, Kozarica and Prožura). Each blatina has a ponor, locally named jaz – a deep shaft which continues through the unexplored karst conduits and has contact with the sea (which is evident from the regular appearance of eels in the blatinas). Jaz functions as an etavelle connected to the sea: during low groundwater levels the sea water penetrates the aquifer causing an increase in salinity which reaches the blatinas. During high groundwater levels fresh water sinks into it and moves the mixing zone toward the sea, causing a decrease in the blatina salinity. Even though in the Adriatic there are islands of similar size, shape and hydrological parameters (as summarized by Terzić (2006) in a hydrological size index), blatinas appear exclusively on Mljet. It is a consequence of an appropriate combination of hydrogeological and morphological features, i.e. the fact that the altitudes of the polje and sinkholes are very close to sea level. Today the blatinas are the main water source which is, after a desalination process, used for the public water supply of the Island of Mljet. However, this was not always the case.

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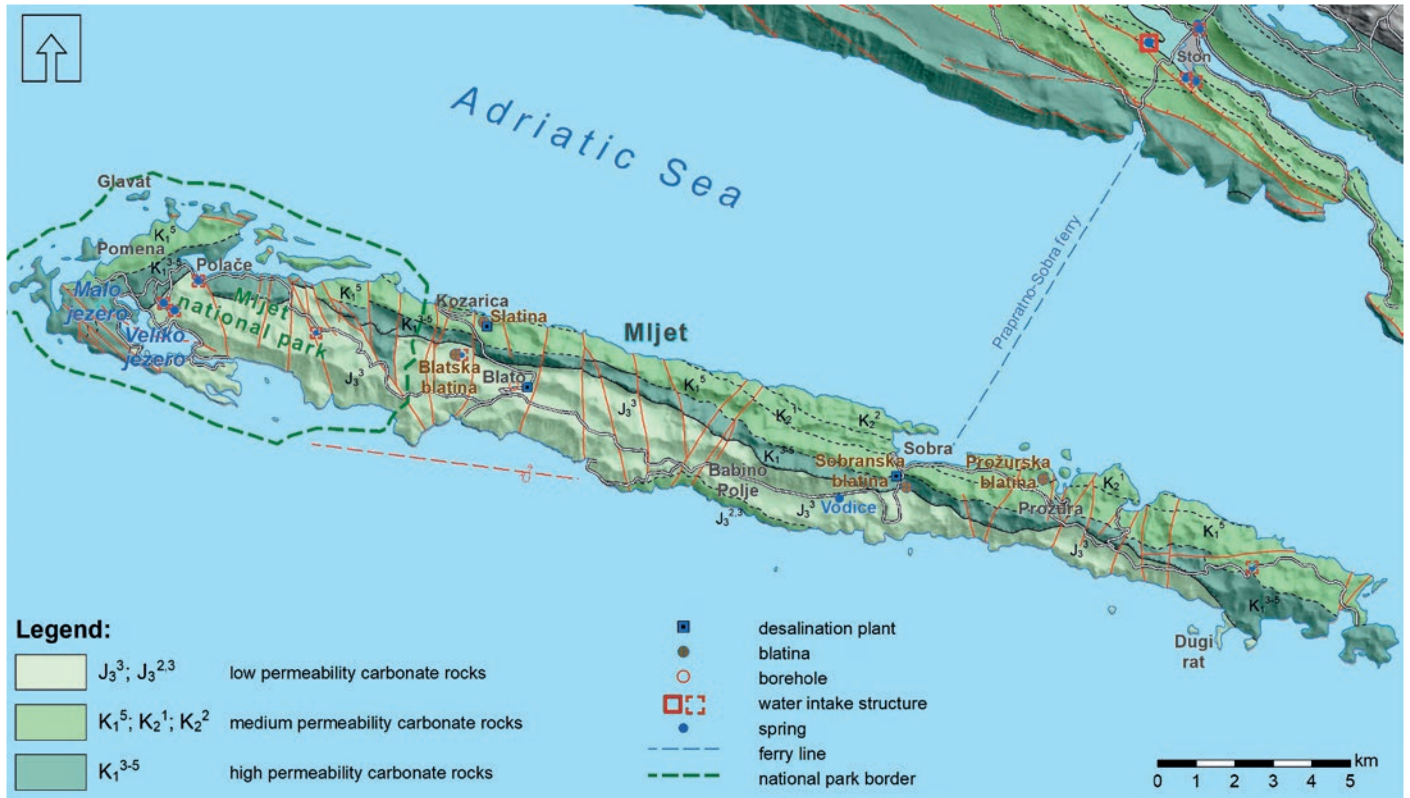

Fig. 10 Geological map of the area

Toward the contemporary water supply

The earliest data concerning hydrogeological research comes from Anić et al. (1953) who were conducting research in order to ensure a local water supply. At that time the small island population was mostly using rainwater from household tanks. The authors described small natural freshwater springs and proposed geophysical research which would determine the locations for two exploration-exploitation wells targeting dolomites in the vicinity of Babino Polje. Considering the blatinas, they deemed those in Sobra, Kozarica and Prožura unfit for water supply purposes and stated that no further research was recommended. However, they proposed the construction of a dug well next to the blatina in the Blatsko polje, the location of which would be determined by detailed hydrogeological mapping and geophysical research.

In 1971 four exploration wells were drilled on the island (Turalija, 1971). The investor (local government) chose the locations and drilled the wells without any hydrogeological research and prior to the arrival of Turalija and associates who were to perform pumping tests. Unsurprisingly, the wells did not show any significant yield (the best one was 0.2 L/s).

Hydrogeological research and pumping tests at a few localities were conducted by Goatti (1996) in order to secure water for the temporary water supply using desalination plants, as a transitional solution until the regional NPKL pipeline was extended from the mainland to Mljet Island. The research has shown favourable conditions, and desalination plants were installed at Sobra, Blato and Kozarica.

After that, Musladin (2000) drilled and tested an additional well in Blato. It had very good characteristics so the temporary water supply was improved.

Water quality

The most thorough interpretation of the hydrochemical analyses of waters from the Island of Mljet was presented in Terzić (2006) and Terzić et al. (2010) and is briefly summarized here. Water sampling was conducted during the autumn of 2005 (hydrological minimum) and the spring of 2006 (maximum) and the results of subsequent analyses are displayed in Table 1.

Table 1 Major ion composition of waters from localities on the Island of Mljet in different seasons

	LOCATION	EC (µS/cm)	T (°C)	pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-
MIN 2005	Spilja intake structure - Sobra	2860	15,7	7,4	153	53,2	329	9,8	399	660	90	1,9
	Zdenci kod Blata	8120	15,9	7,66	160	117	1574	76	410	2240	300	0
	Slatina	6930	22,1	7,5	118	111	1096	70	450	1950	190	0
	Prožurska blatina	32000	26,1	7,79	75	200	5582	102	310	9640	1600	0
MAX 2006	Spilja intake structure - Sobra	1527	15,7	7,61	66,4	20,9	185	3,1	215	340	50	0
	Sobranska blatina	1529	16,2	7,82	66,4	20,9	195	3,1	215	380	51	0
	Wells in Blato	877	14,7	7,59	76,8	25,4	46	2,1	285	86	43	29
	Blatska blatina	2010	14,6	8,23	78,4	25,1	380	3,2	285	754	46,9	39
	Kozarica intake struc-ture	5620	15,2	7,24	126,4	90,8	728	3,4	510	1436	50,1	32
	Slatina	6550	14,7	7,26	127,6	90,6	891	3,4	510	1781	42,5	22
	Prožurska blatina	17170	19,6	8,5	171,2	338,9	2520	52	580	4889	430	0
	Vodice spring	762	14,4	7,55	80,8	35,2	24	1,2	290	47,6	11,2	0
	MAX ALLOWED FOR DRINKING WATER	2500	25	6.6 - 9.5			200	12		250	250	50

Source: Terzić, 2006

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LOCATION	SP (%)
Prožurska blatina	48,2
Prožurska blatina	24,4
Blatska blatina	3,8
Wells in Blato	11,2
Wells in Blato	0,4
Slatina	9,8
Slatina	8,9
Kozarica intake structure	7,2
Sobranska blatina	1,9
Spilja intake structure - Sobra	3,3
Spilja intake structure - Sobra	0,7
Vodice	0,2
HYDROLOGICAL MINIMUM	

Table 2: SP in different locations and seasons.

Source: Terzić, 2006

The percentage of seawater (SP) was calculated by the conservative mixing approach (Appelo & Postma, 1994), according to known values of Cl- ions, using the simplest form of the equation: SP = 0.005[Cl-].

As can be observed in Table 2, the lowest percentage was recorded in the natural spring of Vodice (0.2 %), and the wells in Blato (0.4 %), which was expected. Blatinas generally have higher SP, which is logical due to their proven conduit connections to the sea: Sobranska blatina (1.9 %), Blatska blatina (3.8 %) and Slatina (9 %). The highest SP was recorded in Prožurska blatina (24.4 – 48.2 %, depending on the season), which is not included in the water supply system. That would not be economically feasible due to the fact that the energy consumption for reverse osmosis desalination process increases exponentially with water salinity.

High nitrate ion concentrations were also observed in blatinas, especially during higher groundwater levels. This is attributed to the leaching of nitrates from soil on arable land in karst poljes and from the epikarst zone during the rainy period of the year. Also, in such marshy lakes a significant amount of nitrogen is present in living plants and animals, as well as in their detritus. Ammonification and nitrification occur during their decomposition, which additionally increases the nitrate content in the waters.

Obtained hydrochemical data were also subjected to the multivariate analysis technique of factor analysis. The analysis has shown that three factors can be considered a cause of the 84 % of the total variance of hydrochemical data, when considering Adriatic karst islands in general. Those are: F1 – the mixing of fresh groundwater and surrounding sea water (58 %), F2 – carbonate dissolution (18 %) and F3 – the anthropogenic influence, i.e. nitrate contamination (8 %). In the blatinas of Mljet (Table 3), due to connection to the sea, the F1 factor is present, but the waters range in salinity from almost potable fresh water in Sobra and Blato, to almost 50 % SP in Prožura, where F1 is strongly emphasized in any hydrological moment. In Prožurska blatina there is also a high influence of F2 during the hydrological maximum, pointing to more intense carbonate dissolution in the shallow epikarst zone during rainfall. An interesting fact is that all of the blatinas, unlike other water bodies on Adriatic karst islands, have high positive values of F3 during the hydrological minimum, which implies that the increase in nitrate ion concentrations is not the consequence of leaching from shallow layers, but of ammonification and nitrification which occur during organic matter decomposition.

Table 1 Major ion composition of waters from localities on the Island of Mljet in different seasons

HYDROLOGICAL MINIMUM 2005				HYDROLOGICAL MAXIMUM 2006			
Location	**Factor 1**	**Factor 2**	**Factor 3**	**Location**	**Factor 1**	**Factor 2**	**Factor 3**
Spilja intake structure - Sobra	-0.125	0.725	0.497	Spilja intake structure - Sobra	-0.329	-1.023	0.478
Wells in Blato	1.267	0.786	0.768	Sobranska blatina	-0.362	-1.034	0.767
Slatina	0.810	1.044	1.740	Wells in Blato	-0.201	-0.654	-0.578
Prožurska blatina	5.140	-0.637	1.059	Blatska blatina	0.038	-0.842	-0.418
Factor points				Kozarica intake structure	0.583	0.857	-0.878
Varimax rotation				Slatina	0.680	0.780	-0.689
	dominant process in the system			Prožurska blatina	2.295	1.903	2.328
	very dominant process in the system			Vodice spring	-0.434	-0.580	0.320

Source: Terzić, 2006

INTERMEDIATE STOPS: SOBRA DESALINATION PLANT

From the location of the desalination plant, Sobranska blatina can be observed (62 m of altitude differential). The water intake was displaced from the Blatina itself into the spring in the cave where the groundwater level is the same as in the Blatina, but the water is not heated by insolation and contains less biota. Water is also abstracted from a well close to the Blatina (about 25 m deep; water level slightly higher than in the Blatina), which was drilled after 2005 (between 2007 and 2010, but no reports were found in the documentation). Such a double intake gives in total 25-30 m^3/h (7-8.3 L/s) during the summer and 8-10 m^3/h (2.3-2.8 L/s) during the winter. The majority of the water is pumped from the spring in the cave, while the borehole contributes around 25-30 %, depending on the hydrological situation.

The water conditioning plant consists of a collector tank, chlorination, coagulation, filtration, and osmosis membrane desalination equipment.

The leftover brine is discharged into the sea, also at Sobra, in the Klačna luka bay.

INTERMEDIATE STOP: KOZARICA

The blatina is called Slatina. Its salinity is around 3000 ppm. A small desalination plant has strict local importance, because it only supplies ten households. However, from a touristic point of view it is very attractive because of the evident vicinity of the sea, both laterally and vertically.

Fig. 11 Blatina Slatina in Kozarica

INTERMEDIATE STOPS: BLATSKO POLJE

The bottom of the polje is situated at 35 m a.s.l., and Blatska blatina is situated in its lowest, western part. Water used for a desalination plant here is pumped from two wells which are 40 deep and the pumps are at 37-38 m depth, while the groundwater level is at about 32 m depth. The wells are situated in the eastern part of the polje, around 1 km from blatina and a few metres apart. The wells are 100 mm in diameter, and operate with a total capacity of about 4 L/s. Water salinity ranges between 2500 and 5000 ppm, while the waste water salinity is 8000 ppm. Waste water is discharged into the marsh between the desalination plant and the blatina, which is not best practice for the environment, but for now it seems that neither the vegetation nor the overall blatina salinity has been disturbed.

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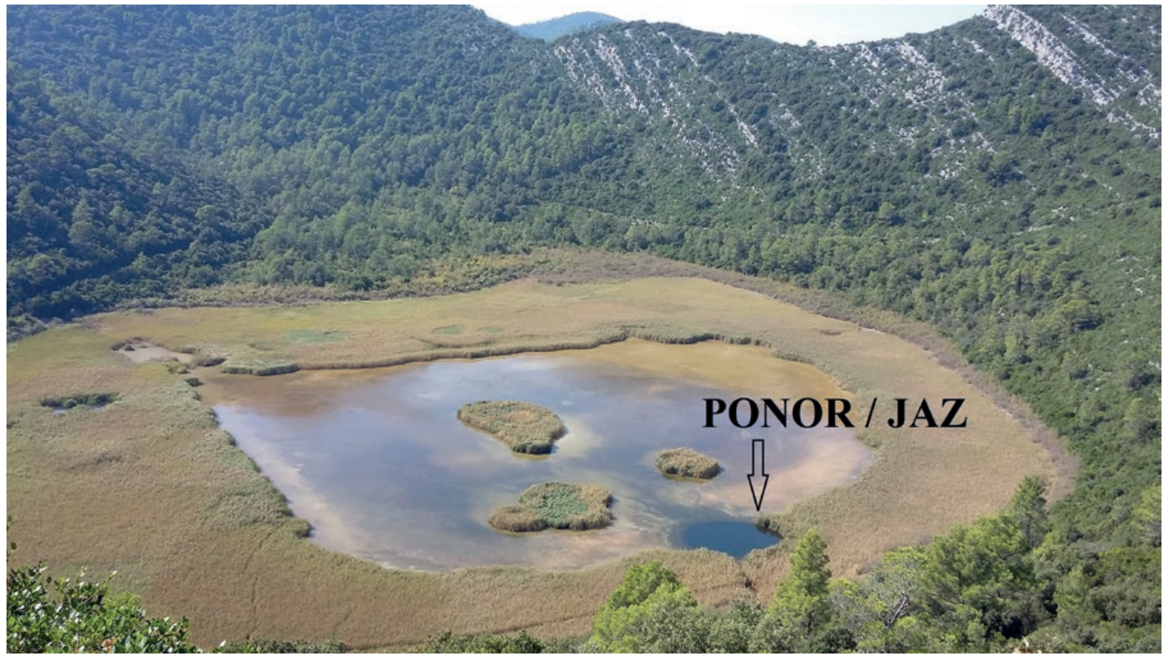

Fig. 12 Blatska blatina

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